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Layered RF Phantom Characterization for Wireless Medical Vital Sign Monitors

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Abstract— Wearable antenna performance measurements were used to characterize a synthetic variable layered phantom test-bed, representative of human tissue for operation in the 868/915 MHz, and 2400 MHz industrial, scientific and medical frequency bands. Antenna radiation efficiency measurements on the phantom were compared with measurements on the thorax region of a human test subject. The results show that the phantom is representative of the human body for the application of wireless vital sign monitors, where conductive connections are made to the tissue.

I. INTRODUCTION

Body centric communications are now one of the most rapidly evolving marketable areas, expected to grow up to more than 400 million devices by 2014. According to present trends, by 2020 at least 160 million Americans will be monitored or treated remotely for at least one chronic condition [1]. The use of biosensors attached to the body for health monitoring is now readily accepted, and the merits of such systems and their potential impact on healthcare have received much attention [2]. It is clear that wearable medical systems, such as Vital Signs Monitors (VSM) need to be comfortable to wear, low size and profile to maintain patient comfort and high efficiency to maintain communications links. Additionally, and vital to the success of these innovations, is that they reliably perform on all patients. Experimental measurement verification platforms, representative of the broad range of human bodies which these devices may operate on, are considerably lagging behind numerical simulating methods [3,4]. In this paper, a novel phantom test-bed is characterized using experimental measurements to address the incompatibility of current tissue simulating phantoms for wearable medical VSM technology.

II. BACKGROUND

Wireless VSM's measure heart rate, temperature and respiration. To do this, they use an impedance harness, which is connected to the skin using conductive electrodes. Broadly, the device incorporates digital processing technology, RF circuitry and an antenna. To comparatively test different antenna designs, a repeatable measurement phantom is required. In this

VSM application, the phantom should be electromagnetically representative of the spread in tissue properties of the thorax region of the human population. Furthermore, to characterize the performance of the antenna, all components must be present, particularly the conductive connection to the body, which may influence the radiation characteristics of the device. An ideal phantom would have variable tissue thicknesses, where the wearable antenna performance bounds could be established to verify that a device operating on a human test subject would fall within the performance bounds, as measured on the test-bed.

Tissue equivalent phantom technology is well established. However, over the past decade, development has been primarily driven by the need to measure human exposure levels to mobile handset antennas [5]. Recently, multiple layer tissue phantoms have been more commonly reported in literature for tumor detection and breast screening research [6]. Phantoms of these types are not optimized and characterized for close coupled VSM antennas, where a broad range of tissue geometries are represented, which is the focus of this work.

III. EXPERIMENTAL MEASUREMENT

A. Human Tissue Phantom

The phantom is a three layer tissue design is based on the geometry of our first generation phantom [3], with increased dimensions width, height and length of 0.3x0.15x0.5m, respectively. The phantom is comprised of a solid skin, with a fat tissue layer and a liquid center layer. This has been enabled by the development of materials for both the skin and fat layers: the former is conductive latex based on graphite powder and the latter is a solid conductive polymer. The inner layer, representative of subcutaneous adipose tissue (SAT) also acts as a container for the liquid core, representing muscle [3]. The materials are representative of tissue properties in the 800-2500 MHz band. Furthermore, the SAT layer thickness can be adjusted by inserting additional close fitting blocks of SAT material. For this study, two SAT layer thicknesses (4 mm and 26 mm) were chosen to give maximum deviation in antenna performance characteristics at the lower frequency limit of 800 MHz, based on return loss ($|S_{11}|$) and radiation efficiency (Fig.1).

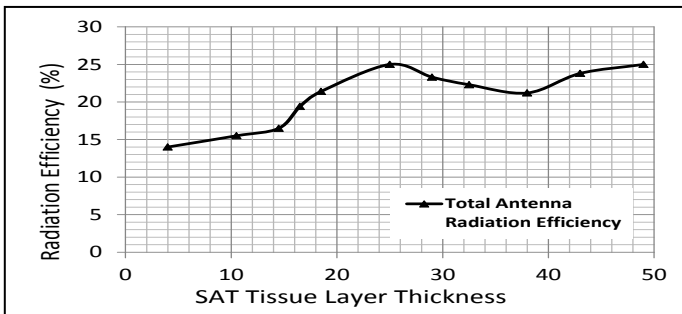


Figure 1. Measured total antenna radiation efficiency at 800 MHz for a dipole antenna mounted parallel to the surface of the phantom as a function of SAT layer thickness.

B. Vital Sign Monitor

Toumaz Healthcare Ltd. develop ultra-low power, ultra-small size body vital signs monitoring systems. A modified Toumaz VSM patch was used in this experimental analysis. The digital and RF circuitry was bypassed and connection was made to the antenna. This was to isolate and directly evaluate the antenna performance when in close proximity to the body and phantom surface. An integrated fractal and fundamental flexible dipole antennas fitted to the VSM patch were used for these verification measurements. Both the dipole and printed antennas were placed parallel and in close proximity to tissue, to enhance the level of antenna-body coupling to amplify any differences between the tissue phantom and the human test subject used for this study. All components of the VSM were present in the VSM measurements. Particular attention was given to the conductive electrode connection to the skin and outer phantom layer, which is essential to the operation of the VSM system. This conductive connection, also affects the current distributions on the unit and antenna, and thus the coupling and radiation characteristics of the device.

C. Measurement Description

The return loss ($|S_{11}|$) and the radiation efficiency of the VSM antenna were measured on the physical tissue phantom. The measurements were repeated for VSM system mounted on the thorax region of an adult male of 70 Kg and 180 cm, weight and height, respectively. All measurements were performed in a 3 m by 3 m by 3 m reverberation chamber. The main advantage of the chamber is that it can be used for live measurements as any test subject movements will positively contribute to additional modes, thereby reducing measurement uncertainty. The antennas were mounted 5 mm from the body surface using Rohacell HF51 foam ($\epsilon_r=1.07$), on the thorax of the test subject, consistent with the phantom measurements. The test subject was asked to minimize the risk of changing the antenna-body separation, but it is inevitable that there were breathing effects and other minor body movements.

D. Results and Discussion

The radiation efficiency of an integrated fractal antenna on a thorax mounted VSM was measured on a test subject and compared to measurements on the phantom test bed (Fig. 2). Results show that the radiation efficiency on the phantom is very representative of the same measurement on a human body, as the body measurements lay between the performance bounds of the phantom. For this test subject, the results are a closer fit to the phantom with a minimum SAT layer thickness.

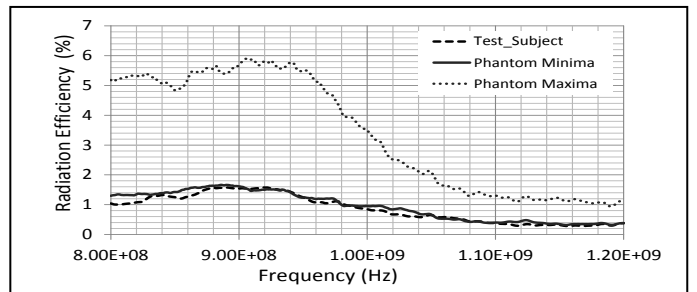


Figure 2. Comparison of total antenna radiation efficiency for a VSM antenna on the thorax of a human test subject and on a phantom test-bed.

Radiation efficiency measurements using a fundamental dipole antenna versus a human test subject are detailed in Table I. The total radiation efficiency results include the impedance mismatch at the antenna. Results show that the human test subject efficiencies fall within the efficiency bounds of the phantom test bed at both ISM band frequencies.

IV. CONCLUSIONS AND FUTURE WORK

This measurement analysis shows that the phantom test-bed proposed is a promising platform for the development and measurement of wireless VSM systems. Future work will optimize the test-bed to be representative of the broad range of human thorax tissue compositions of the human population, which impact the antennas and propagation performance of a VSM. This will include a comparative analysis on multiple test subjects, with a broad range of tissue geometries.

TABLE I. MEASURED DIPOLE ANTENNA EFFICIENCY.

Antenna/ Frequency (Mhz)	Antenna Location	Total Radiation Efficiency	Radiation Efficiency (No Mismatch)
Dipole/800	Phantom Minima	14 %	14 %
Dipole/800	Phantom Maxima	25 %	25 %
Dipole/800	Test-Subject Thorax	14.5 %	14.5 %
Dipole/2400	Phantom Minima	24 %	25 %
Dipole/2400	Phantom Maxima	34 %	35 %
Dipole/2400	Test-Subject Thorax	29.8 %	30 %

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